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INCLUSIVE MEASUREMENT OF THE STRONG COUPLING AT HERA

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Abstract

We describe the measurement of the strong coupling α_s from data on inclusive DIS at high energies. We present new results using the 1994 data from H1, and confirm directly the expected running of α_s .

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We describe the measurement of the strong coupling α_s from data on inclusive DIS at high energies. We present new results using the 1994 data from H1, and confirm directly the expected running of α_s .

Determining the strong coupling α_s from fixed target inclusive deep inelastic scattering¹ requires very precise measurements of structure functions at large x over a wide range of Q^2 in order to extract the relatively small violations of Bjorken scaling. In colliding beam deep inelastic scattering experiments, such as are now being performed at HERA, structure functions may be measured at small x , where Bjorken scaling violations are much stronger. Indeed the steep rise in $F_2(x, Q^2)$ as $1/x$ and Q^2 both increase is driven essentially by the three-gluon vertex², resulting asymptotically in a new double scaling behaviour³. The predicted slope of the rise in F_2 has been confirmed very precisely using the recent HERA data^{4–6}, and two loop corrections are now discernible^{7–10}. Since the three gluon vertex is itself directly proportional to α_s , the success of double scaling immediately suggests³ that $F_2(x, Q^2)$ must be rather sensitive to the value of α_s in the double scaling region, and indeed this expectation is confirmed by simple double scaling fits to the data which include α_s as a free parameter^{13,9}.

Of course a proper determination¹³ of α_s from F_2 at small x requires a full two loop calculation which matches on to all the other data (and in particular structure function and prompt photon data) at large x . Care must also be taken to disentangle the effects of higher twists and higher logarithms (of $1/x$): fortunately this turns out to be rather easier than at large x , where the effects of both higher twists and infrared logarithms (of $1 - x$) may become very significant. Here we will briefly review how such a small x determination

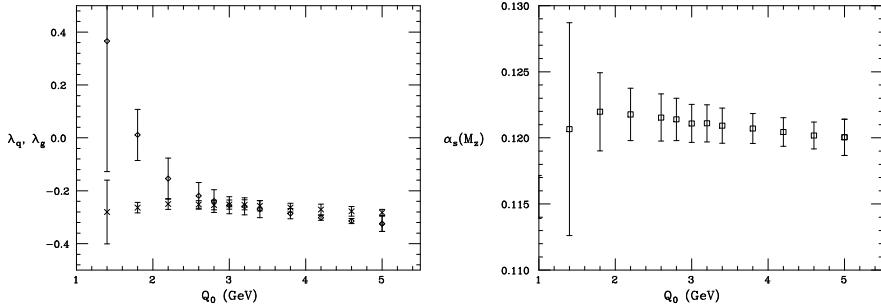


Figure 1: The three fitted parameters ($\lambda_q, \lambda_g, \alpha_s(m_Z)$) for a range of values of Q_0 . The distribution is fitted and evolved in $\overline{\text{MS}}$.

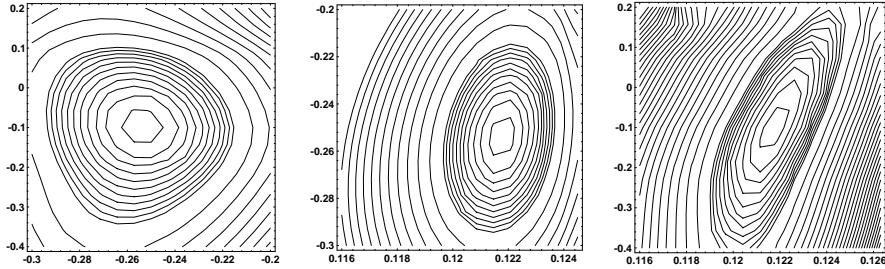


Figure 2: Contour plots of χ^2 in the three orthogonal planes (λ_q, λ_g) , $(\alpha_s(m_Z), \lambda_q)$ and $(\alpha_s(m_Z), \lambda_g)$ through the global minimum. The first eleven contours are at intervals of one unit, while those thereafter are at intervals of five units. The starting distribution is in $\overline{\text{MS}}$ at $Q_0 = 2\text{GeV}$. To compute the χ^2 statistical and systematic errors are combined in quadrature, and the normalization uncertainties included: at the minimum $\chi^2 = 80$ for 166 degrees of freedom, the normalizations are within 1% of the experimental values.

may be performed, and then present some preliminary results obtained using the most recent data⁸ from the H1 collaboration.

Our basic procedure^{11,13} is to take a set of globally fitted parton distributions, for example those of CTEQ¹⁶ or MRS¹⁷, evolve them (using a two loop evolution code) to some new starting scale Q_0 , and there cut off the tails of the sea and gluon distributions, replacing them with new tails $xq \sim x^{\lambda_q}$, $xg \sim x^{\lambda_g}$ for $x \lesssim 0.01$.* These new distributions, together with the valence distributions, are evolved up (or down) to the HERA data, again at two loops, using a particular value of $\alpha_s(m_Z)$. The three parameters $(\lambda_q, \lambda_g, \alpha_s(m_Z))$ are then adjusted to minimise the χ^2 to the data. The final distributions are by

* In practice this is achieved by refitting the large x distributions at Q_0 with λ_q and λ_g kept fixed.

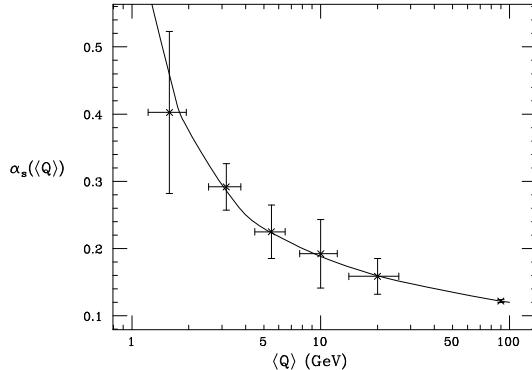


Figure 3: The strong coupling measured independently at five different scales. The horizontal bars indicate the width of each bin. The curve shows the theoretical two loop running when $\alpha_s(m_Z) = 0.122$ (the sixth point). The points are over-correlated due to correlated systematics.

construction a reasonable fit to all the data with $x \gtrsim 0.01$ used to determine the original input distributions, since QCD evolution is causal in x . However the shape of the distributions in the HERA region is largely independent of the details of the input, since asymptotically it takes a universal (double scaling) form which depends rather sensitively on the value of α_s .³ Higher order effects due to choosing large x distributions which have been fitted using different values of α_s should in principle also be included. In this sense our procedure is similar to that used to determine α_s from, for example, the 2 + 1 jet rate at HERA, or the inclusive jet rate at the Tevatron.

The results of such fits to the H1 1994 data⁸ for a range of values of Q_0 are presented in fig. 1. The stability of the fitted value of α_s in the region where the χ^2 is lowest ($2 \text{ GeV} \lesssim Q_0 \lesssim 4 \text{ GeV}$) is a useful test of the effectiveness of the parametrization employed at Q_0 . More information about the shape of the minimum in the χ^2 at a particular value of Q_0 is displayed in the contour plots fig. 2. The third plot shows that although the shape of the inferred gluon distribution and α_s are indeed correlated, this does not lead to a large uncertainty in α_s because of the close relation between the quark and the gluon shown in the first plot: very steeply rising or falling gluon distributions at 2 GeV are incompatible with the double scaling seen in the H1 data. This explains why it is possible to determine α_s at small x even though the gluon distribution is large there.

Our preliminary result using the H1 1994 data is $\alpha_s(m_Z) = 0.122 \pm 0.004(\text{exp})$. The theoretical error has not yet been determined, but should be a little less than that found¹³ in our analysis of the 1993 data, partly because the data themselves now severely limit the allowed size of corrections due

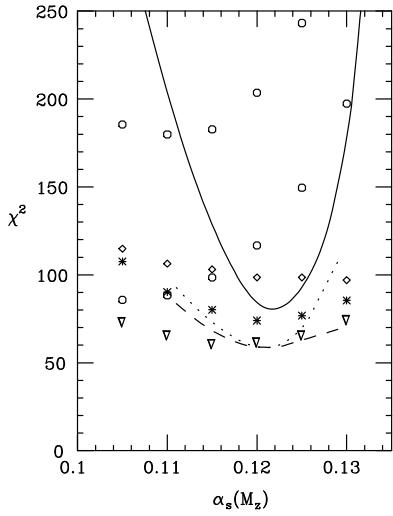


Figure 4: Contributions to the total χ^2 from various structure function data sets included in global fits at six different values of $\alpha_s(M_Z)$, adapted from ref.14. The data are from BCDMS F_2 (open squares, 142 points), NMC F_2 (open diamonds, 74 points), CCFR F_2 (open circles, 80 points), CCFR F_3 (open triangles, 80 points), and HERA F_2 (asterisks, 93 points from H1 + 56 from ZEUS, both from the 1993 run). The curves are also from fits to HERA F_2 data: the dotted ($\lambda_q = \lambda_g$) and dashed ($\lambda_q \neq \lambda_g$) curves using 1993 data (122 points) are from the analysis in ref.13, while the solid curve is from this analysis (H1 1994 data, 169 points). In all these curves $\alpha_s(M_Z)$ in the large x input distribution was kept fixed.

to higher order logarithms of $1/x$.¹⁰ The error due to higher twist corrections seems also to be very small, since their size is again limited by the data.¹⁰ Furthermore the allowed range of variation of renormalization and factorization scales can now be limited by requiring that the fit to the data is not unduly worsened. A more complete analysis will be made when all the ZEUS 1994 data have been published.

By only including some of the data in the fit, over a limited range of Q^2 , we can actually perform independent measurements of α_s at different scales. The results of such a procedure are displayed in fig. 3. It is gratifying to observe directly the running of α_s in a single experiment. Of course we already knew that this had to work: the slope of the rise of F_2 is in itself a direct measurement of the first coefficient of the β -function.⁴

It is important to emphasise that our determination uses only HERA data directly: it is not a global fit. Some of the advantages and disadvantages of the two techniques may be seen by comparing our results to those of the subsequent MRS global fits described in ref.14 (see fig. 4), or indeed to very similar results from CTEQ.¹⁶ In a global fit the χ^2 for each data set are in general simply

added together, irrespective of the fact that different experimental collaborations may treat their errors rather differently. The data from BCDMS then dominate the determination of α_s not because there are many more points, but because the χ^2 per point turns out to be relatively large (a better fit to these data, with more parameters, was obtained in ref.1). Indeed the minima in the χ^2 of the NMC and CCFR F_2 data actually disappear in the MRS global fit. The minimum in the 1993 HERA data is uncorrupted, however, and is indeed consistent both in position and width with the direct analysis of ref.13: this is to be expected as the shape of F_2 at small x is largely independent of the detailed structure at large x .³ Note that the global analysis¹⁴ has $\lambda_q = \lambda_g$: relaxing this constraint softens the minimum but does not eliminate it. The present analysis of the 1994 data shows that in the future HERA structure function data will begin to play an increasingly significant role in the global fitting of α_s (although our solid curve in fig. 4 will presumably not fall quite so steeply once α_s is varied in the input distribution). It is interesting that the relatively high value of α_s favoured by HERA is also found in analyses of the CDF and D0 inclusive jet data.^{15,16,17}

In conclusion, F_2^p at small x and large Q^2 is an excellent place to measure α_s : the data is now very precise, the dependence on α_s is strong, one need only do simple fits with a small number of parameters, while on the theoretical side uncertainties due to higher logarithms seem to be unexpectedly small, while higher twists are truly negligible. Furthermore one can perform a direct test of the running of α_s at spacelike Q^2 in one experiment. We hope that soon experimentalists will perform their own determinations, taking properly into account the correlations of their systematic errors.

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